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Monterey, California

# THESIS

## COMPUTER PROGRAM ANALYSIS OF HELICOPTER WEIGHT ESTIMATE RELATIONSHIPS UTILIZING PARAMETRIC EQUATIONS

by

Rudolph T. Schwab

June 1983

Thesis Advisor: Donald M. Layton

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The computer program consists of several subroutines and will

compute system weight estimates according to Military Standard 1374A. Three categories of military helicopters can be designed; observation, utility, and cargo. Detailed knowledge of helicopters is not required.

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# Computer Program Analysis of Helicopter Weight Estimate Relationships Utilizing Parametric Equations

by

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Captain, United States Army
B.S., United States Military Academy, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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This thesis gives the user of an HP-41CV handheld programmable calculator or the IBM 3033 computer, acceptable results of helicopter system weight estimations during the preliminary design phase.

The computer program consists of several subroutines and will compute system weight estimates according to Military Standard 1374A. Three categories of military helicopters can be designed; observation, utility, and cargo. Detailed knowledge of helicopters is not required.

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# I. INTRODUCTION

## A. BACKGROUND

The estimation of the weight of a helicopter is an essential preliminary step in design procedure. The aerospace industry uses large complex computer programs with hundreds of inputs in order to obtain the predicted weight of the various helicopter systems. This, of course, is the most accurate method in determining precise weights needed in actual design and construction. However, these programs require a detail knowledge of the components and materials to be used, which are not normally available outside the industry. Therefore, another method using the HP41-CV hand held calculator or the IBM 3033 was undertaken that would give acceptable results while providing instantaneous solutions. To date, no known programs of this type have been designed for the HP41-CV or IBM 3033.

## B. GOALS

The objective of this study is to provide a self-prompting, alpha-numeric computer program for helicopter weight estimates. In addition it is to be used by Aeronautical Engineering students at the Naval Postgraduate School enrolled in the Helicopter Design and Advanced Helicopter Design courses.

# II. APPROACH TO THE PROBLEM

The basic approach was to write a computer program on the IBM 3033 using Fortran IV and converting this program to HP41-CV usage. The program consists of the following subroutines:

A. Input
B. Output
C. Observation
D. Utility
E. Cargo

This method greatly reduces the amount of computer memory required. Subroutines Observation, Utility, and Cargo are independent of each other and dependent only on the Input and Output subroutines.

These subroutines use parametric equations derived from the best curve fit of the various system weights. Detailed knowledge of helicopter weights is not required, however, a basic knowledge of helicopter chacteristics and aerodynamics, along with proficiency in either the IBM 3033 or HP41-CV is required.

# III. THE SOLUTION

Weight data was collected for 14 military helicopters. These helicopters were separated into three categories; observation, utility, and cargo. This provided a more accurate weight estimate relationship (WER) for the 18 systems as provided by Military Standard 1374A (Table I). Due to the selection of helicopters, a WER for the wing was not required. The air conditioning and anti-icing weights were combined into one WER. The data was obtained from actual military records located at Fritsche Army Airfield , Ft. Ord, California, [Ref. 1] and Edwards Air Force Base, Ca. [Ref. 2]. In addition Jane's All The Worlds Aircraft [Ref. 3], Jane's Pocketbook of Helicopters [Ref. 4], and NASA CR152315 [Ref. 5] were used. The data are summarized in Table II.

In analyzing the data design gross weight was the major correlating factor in determining the individual system weights. There are eight factors that affect gross weight; empty weight, blade planform area, number of personnel, personnel weight, fuel, horsepower, cargo weight, and number of engines.

Utilizing these factors and an HP41-CV curve fit program, parametric equations were obtained for each of the helicopter systems, providing acceptable results for establishing preliminary design weights. The equations for each type helicopter are found in Table III. Example problems for the HP-41CV and IBM 3033 are contained in Appendix A and Appendix B.

## TABLE I

## Helicopter Systems

1. Rotor
2. Tail
    - A. Tail Rotor
    - B. Tail Structure
3. Body
4. Landing Gear
5. Nacelle
6. Propulsion
    - A. Engine
    - B. Drive
    - C. Fuel Tanks
7. Flight Controls
8. Auxiliary Power
9. Instruments
10. Hydraulics
11. Electrical
12. Avionics
13. Furnishings and Equipment
14. Air Conditioning and anti-icing
15. Load and Handling

---

These systems correspond to the 18 standard weight groups defined in Military Standard 1374A, except pneumatics, wing, and armament have been deleted while air conditioning and anti-ice were combined.

## TABLE II

## Helicopter System Weight Summary

| MODEL | Empty Weight We | Gross Weight Wg | Main Rotor W1 | Rotor Planform S(sq ft) |
|---|---|---|---|---|
| OH-6A | 1202 | 2400 | 174 | 26.0 |
| TH-57A | 1535 | 2900 | 277 | 31.9 |
| OH-58A | 1545 | 3000 | 281 | 33.9 |
| OH-13S | 1926 | 2850 | 284 | 32.5 |
| OH-4A | -- | -- | 250 | 28.8 |
| UH-1H | 5235 | 9500 | 742 | 76.9 |
| H-52A | 5585 | 8310 | 785 | 92.5 |
| UH-19D | 5831 | 7100 | 786 | 92.5 |
| UH-60A | 10222 | 20250 | 1705 | 160.0 |
| CH-34A | 7803 | 14000 | 1313 | 129.1 |
| CH-46F | 13313 | 23000 | 2424 | 136.5 |
| CH-47A | 17752 | 33000 | 2996 | 315.7 |
| CH-53A | 23097 | 40000 | 4489 | 348.7 |
| CH-37A | 21238 | 30342 | 3251 | 272.6 |

| MODEL | Tail W2 | Tail Rotor W2A | Tail Struc W2B | Surface Area Stt(sq ft) |
|---|---|---|---|---|
| OH-6A | 23 | 7 | 16 | 12.3 |
| TH-57A | 34 | 8 | 26 | 19.9 |
| OH-58A | 132 | 10 | 22 | 18.6 |
| OH-13S | 17 | 8 | 9 | 8.7 |
| OH-4A | 118 | 11 | 7 | 7.9 |
| UH-1H | 384 | 30 | 54 | 31.3 |
| H-52A | 106 | 53 | 53 | 37.0 |
| UH-19D | 101 | 60 | 41 | *23.8 |
| UH-60A | 346 | 105 | 241 | 106.4 |
| CH-34A | 260 | 74 | 186 | 75.3 |
| CH-46F | 0 | 0 | 0 | 0.0 |
| CH-47A | 0 | 0 | 0 | 0.0 |
| CH-53A | 673 | 367 | 306 | 93.4 |
| CH-37A | 570 | 345 | 225 | 112.0 |

| MODEL | Body W3 | Body Surface Sb (sq ft) | Landing Gear W4 | Type Gear |
|---|---|---|---|---|
| OH-6A | 242 | 205 | 70 | skid |
| TH-57A | 335 | 244 | 45 | skid |
| OH-58A | 332 | 247 | 35 | skid |
| OH-13S | 221 | 121 | 54 | skid |
| OH-4A | 359 | 243 | 43 | skid |
| UH-1H | 1035 | 626 | 121 | skid |
| H-52A | 1263 | 849 | 485 | roll |
| UH-19D | 985 | 640 | 287 | roll |
| UH-60A | 1729 | 805 | 659 | roll |
| CH-34A | 1044 | 817 | 475 | roll |
| CH-46F | 3126 | 1452 | 591 | roll |
| CH-47A | 4487 | 2150 | 1086 | roll |
| CH-53A | 5260 | 2587 | 1019 | roll |
| CH-37A | 3247 | 1553 | 983 | roll |

---

* Not used in developing WER

### Table II (cont)

### Helicopter System Weight Summary

| MODEL | Nacelle W5 | Engine Type # | Number of Engines | Propulsn System W6 |
|---|---|---|---|---|
| OH-6A | *8 | 2 | 1 | 341 |
| TH-57A | 32 | 2 | 1 | 416 |
| OH-58A | 36 | 2 | 1 | 419 |
| OH-13S | 37 | 1 | 1 | *845 |
| OH-4A | *25 | 2 | 1 | 390 |
| UH-1H | 114 | 2 | 1 | 1632 |
| H-52A | 63 | 2 | 1 | 1115 |
| UH-19D | 147 | 1 | 1 | 2525 |
| UH-60A | 155 | 2 | 2 | 2730 |
| CH-34A | 150 | 1 | 1 | 3189 |
| CH-46F | 71 | 2 | 2 | 3235 |
| CH-47A | 176 | 2 | 2 | 5151 |
| CH-53A | 394 | 2 | 2 | 6057 |
| CH-37A | *1098 | 1 | 2 | 8419 |

| MODEL | Eng W6a | Drive W5b | Fuel Tanks W6c | Horse-power HP |
|---|---|---|---|---|
| OH-6A | 192 | 113 | 36 | 250 |
| TH-57A | 194 | 176 | 36 | 317 |
| OH-58A | *165 | 215 | 39 | 317 |
| OH-13S | *588 | *155 | *102 | 260 |
| OH-4A | 1998 | 159 | *32 | 250 |
| UH-1H | 683 | 658 | 291 | 1103 |
| H-52A | 360 | 621 | *134 | 1050 |
| UH-19D | 1244 | *1064 | 217 | 800 |
| UH-60A | 862 | 1405 | 463 | 3036 |
| CH-34A | 1737 | 1091 | 361 | 1525 |
| CH-46F | 951 | 2010 | 274 | 2600 |
| CH-47A | 1342 | 3531 | 278 | 4400 |
| CH-53A | 1762 | 3913 | 376 | *5700 |
| CH-37A | *5516 | 2567 | 336 | 4200 |

| MODEL | Fuel Quantity G (gals) | Flight Controls W7 | Aux W8 | Instru-ments W9 |
|---|---|---|---|---|
| CH-6A | 62 | 65 | 0 | 30 |
| TH-57A | 76 | 133 | 0 | 29 |
| OH-58A | 73 | 125 | 0 | 27 |
| OH-13S | -- | -- | 0 | 24 |
| OH-4A | -- | -- | 0 | -- |
| UH-1H | 211 | 357 | 0 | 59 |
| H-52A | 325 | 353 | 0 | 124 |
| UH-19D | 175 | *164 | 0 | 70 |
| UH-60A | 343 | 694 | 164 | 152 |
| CH-34A | 263 | 378 | 0 | 108 |
| CH-46F | 380 | 828 | 106 | 158 |
| CH-47A | 620 | 1212 | 99 | 172 |
| CH-53A | 638 | 1168 | 211 | *395 |
| CH-37A | 410 | 965 | 0 | 191 |

---

* Not used in developing WER

# Engine types: 1- reciprocating; 2 - turboshaft

## Table II (cont)

## Helicopter System Weight Summary

| MODEL | Hydraulics W10 | Electrical W11 | Avionics W12 | Furnish & Equip W13 |
|---|---|---|---|---|
| OH-6A | 0 | 68 | 113 | 58 |
| TH-57A | 0 | 110 | -- | 64 |
| OH-58A | 0 | 85 | 106 | 42 |
| OH-13S | 0 | 130 | 91 | 30 |
| UH-1H | 33 | 360 | 246 | 408 |
| H-52A | 43 | 419 | 427 | 216 |
| UH-19D | 47 | 327 | *110 | 205 |
| UH-60A | 87 | 464 | 466 | 675 |
| CH-34A | 26 | 327 | 269 | 189 |
| CH-46F | 168 | 654 | 645 | 854 |
| CH-47A | 212 | 555 | 303 | 866 |
| CH-53A | 132 | 601 | 659 | 1289 |
| Ch-37A | 129 | 497 | *269 | 810 |

| MODEL | Air & Ice W14 | Load & Handling W15 | Number Crew | Number Passengers |
|---|---|---|---|---|
| OH-6A | 10 | 0 | 1 | 2 |
| TH-57A | 27 | 0 | 3 | 0 |
| OH-58A | 25 | 0 | 2 | 0 |
| OH-13S | 40 | 0 | -- | -- |
| OH-4A | -- | 0 | 1 | 1 |
| UH-1H | 44 | 0 | 2 | 11 |
| H-52A | 97 | 89 | 3 | -- |
| UH-19D | 77 | 0 | 2 | 10 |
| UH-60A | 86 | 80 | 3 | 11 |
| CH-34A | 72 | 3 | 2 | 14 |
| CH-46F | *257 | 196 | 3 | 22 |
| CH-47A | 179 | 258 | 3 | 32 |
| CH-53A | *311 | 439 | 3 | 37 |
| CH-37A | 176 | *12 | -- | -- |

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* Not used in developing WER

# TABLE III

## Observation Helicopter Weight Estimating Relationships

| | |
|---|---|
| 1. Rotor | W1 = 408.562 * ln(S) - 1142.917 |
| 2. Tail | |
| Rotor | W2A = 2.219 * exp(.0005 * Wt) |
| Structure | W2B = 19.131 * ln(Stt) - 32.414 |
| 3. Body | W3 = .00901 * Sb**1.917 |
| 4. Landing Gear | W4 = -.0539 * Wg + 200.912 |
| 5. Nacelle | W5 = 34.0 |
| 6. Propulsion | |
| Engine | W6A = -.0896 * Hp + 221.388 |
| Drive | W6B = 17.190 * exp( .0008 * Wg) |
| Fuel Tanks | W6C = .384 * (Fuel/6.5)**1.0710 |
| 7. Flight Controls | W7 = .000000000128 * Wg**3.469 |
| 8. Aux Power | W8 = 0.0 |
| 9. Instruments | W9 = 24.571 * exp(.0004 * Hp) |
| 10. Hydraulics | W10 = 0.0 |
| 11. Electrical | W11 = -51.0661*ln(Sb)+367.947 |
| 12. Avionics | W12 = 1062.00451 - 122.282 * ln(1120.354 *exp(.003*Hp)) |
| 13. Furnisings | W13 = 19.800 * (exp(.372 *People) + exp(-.033*Sb)) |
| 14. Air & ice | W14 = -22.371 * ln(Sb) + 143.396 |
| 15. Load & Handling | W15 = 0.0 |

### Symbols Used In WER

| | |
|---|---|
| People | Number of crew and personnel |
| Sb | Body surface area (sq ft) |
| Wg | Gross Weight (lbs) |
| We | Manufacturers Empty Weight (lbs) |
| S | Main rotor planform area (lbs) |
| Hp | Shaft Horse Power (lbs) |
| Fuel | Amount of fuel (lbs) |
| Stt | Total tail surface area (sq ft) |

### APPROXIMATIONS

Gross Weight
Wg=173.701 * We**.378
Tail Surface Area
Stt=.264 * exp(.0135*Hp)
Body Surface Area
Sb=194.274 * ln(Wg) - 1306.779

## Table III (con't)

## Utility Helicopter Weight Estimating Relationships

| | | |
|---|---|---|
| 1. | Rotor | W1 = 11.0702 * S - 168.888 |
| 2. | Tail | |
| | Rotor | W2A = .00438 * Wg + 12.470 |
| | Structure | W2B = 2.411 * Stt - 19.531 |
| 3. | Body | W3 = .282 * Sb**1.272 |
| 4. | Landing Gear | W4 = .025 * exp(.000062*Wg+8.020) |
| | | #W4 = 301.577 * ln(Wg)-2319.890 |
| 5. | Nacelle | W5 = .02 * exp(.000062*Wg + 8.02) |
| 6. | Propulsion | |
| | Engine | W6A = 130.0 + .451 * Hp |
| | | *W6A = 295.0 + .188 * Hp |
| | Drive | W6B = 741.460 * ln(Hp) -4542.0420 |
| | Fuel Tanks | W6C = 363.240 * ln(Fuel/6.5) -1656.521 |
| 7. | Flight Controls | W7 = 210.858 *exp(.000059 * Wg) |
| 8. | Aux Power | W8 = 0.0 |
| | | *W8 = 190.0 |
| 9. | Instruments | W9 = 56.0975 * ln(Hp) - 312.237 |
| 10. | Hydraulics | W10 = .00362 * Wg + 11.553 |
| 11. | Electrical | W11 = 481.735 * ln(Sb) - 2794.530 |
| 12. | Avionics | W12 = .139 * Hp + 77.823 |
| 13. | Furnishings | W13 = .175*Sb + 22.0*People - 10.0 |
| 14. | Air & ice | W14 = 122.458 * ln(Sb) - 730.252 |
| 15. | Load & handling | W15 = 84.5 |

### Approximations

Gross Weight
Wg = 16239.430 * ln(We) - 130252.760
Tail Surface Area
Stt = .0376 * Hp - 8.106
Body Surface
Sb = 636.081 * exp(.000011 * Wg)
*Helicopters with two engines
#Gross Weight greater than 6000 lbs.

## Table III (con't)

### Cargo Helicopter Weight Estimating Relationships

| | | |
|---|---|---|
| 1. Rotor | | W1 = 707.174 * exp(.00539 * S) |
| | | **W1 =1414.348 * exp(.00539 * S) |
| 2. Tail | Rotor | W2A = 324.550*ln(Wg)-3021.510 |
| | Structure | W2B = -18.0 + 2.830 * Stt |
| 3. Body | | W3 = 2.9818 * Sb - 1321.921 |
| | | **W3 = 3467.291*ln(Sb)-22118.298 |
| 4. Landing Gear | | W4 = 258.358 * EXP(.000041 * Wg) |
| 5. Nacelle | | W5 = .014 * ( .2041*wg )**1.136 |
| 6. Propulsion | Engine | W6A = 348.0 + .910 * Hp |
| | | **W6A = 565.507 * exp(.000198*HP) |
| | Drive | W6B = .999 * Hp**.959 |
| | Fuel Tanks | W6C = 454.619*(Fuel/6.5)**(-.0566) |
| 7. Flight Controls | | W7 = .00334 * WG**1.224 |
| 8. Aux Power | | W8 = 139.0 |
| 9. Instruments | | W9 = 68.266 * ln(Hp) - 387.598 |
| 10. Hydraulics | | W10 = .000000563 * Wg**1.863 |
| 11. Electrical | | W11 = 9.780 * Sb**.539 |
| 12. Avionics | | W12 =(16744.967*ln(Hp)-108666.0)**.536 * 1.90 |
| 13. Furnishings | | W13 = .159 * Sb + 18.11 * People |
| 14. Air & Ice | | W14 = 117.771 * ln(Sb) - 710.594 |
| 15. Load & Handling | | W15 =-72.0 +.111*Sb + 3.490*People |

### Approximations

Gross Weight
Wg = 4.975 * We**.887
Tail Surface Area
Stt = 60.127 * exp(.000145 * Hp)
Body Surface Area
Sb = 426.378 * exp(.000045 * Wg)
**Tandem Helicopter
Stt = 0.0
Sb = 567.688 * exp(.000041 * WG)

## IV. SYSTEM DESCRIPTION

This section provides a detailed discussion of each system as described by Beltramo [Ref. 5] and summarized in Table II.

### A. ROTOR

The rotor system consists of the blade assembly and the hub and hinge assembly. The blade assembly includes the interspace structure, leading and trailing edges, tips(if not integral), balance weights, and mounting hardware and blade foldings. The hub and hinge assembly includes the yoke, universal joints, shafting between the rotor system and the drive box, spacers and bushings, lubrication system, fittings, pins, drag brace, retention strap assembly, and fasteners and misscellaneous hardware.

### B. TAIL

The tail system includes all the aerodynamic surfaces and the mounts for the tail rotor. Tandem helicopters are not considered to have a tail.

### C. BODY

The body consists of the fuslage shell structure, door and window frames, floors, bulkheads, cockpit windshield, and radome. Door actuation mechanisms, airstairs (when installed) and loading ramps are also included.

## D. LANDING GEAR

The system includes landing gear structure, which is made up of struts, side and drag braces, trunnions and attachment fittings. The landing gear controls include components for braking, steering and retraction (if available). For wheel type landing gear this also includes wheels, brakes and tires.

## E. NACELLE

This includes the engine mount, firewall and cowl structure, engine air inlet, oil cooler scoop and miscellaneous installation hardware.

## F. PROPULSION

The propulsion system includes three main subsystems: the engine, drive, and the fuel system. The engine includes the dry engine, residual fluids and installation hardware as well as related components: starter, air inductor,exhaust and cooling items, lubrication systems and the engine controls. The drive subsystem includes the gear speed reducers, tranmission drive, rotor brake and shaft, and lube system. The fuel subsystem includes the fuel fill and drain system, fuel distribution system, fuel vent plumbing and fuel tanks.

## G. FLIGHT CONTROLS

This system includes: cabin controls (cyclic control column, collective pitch levers and rudder or tail rotor pedal); mechanical operating mechanism (swash plate, stablizing bar,linkages, bearings, and levers, bellcranks); hydraulic controls; fluid; and miscellaneous hardware.

## H. AUXILIARY POWER

The auxiliary power system supplies all power for ground operations in lieu of ground support equipment. These operations include: cabin ground air conditioning, engine starting, and driving a generator for electric power.

## I. INSTRUMENTS

Instruments perform basic monitoring and warning functions associated with the flight of the helicopter: electrical, hydraulic and pneumatic systems operation, engine operation and fuel quantity. The instrument system includes cockpit indicators and warning lights, tranducers, signal inputs, circuitry, and the monitoring devices.

## J. HYDRAULICS

The hydraulic system consists of the pumps, reservoirs, filters, accumulators, regulators, valves, manifolds, plumbing, fluid, and supports, and mounting hardware.

## K. ELECTRICAL

The electrical system supplies power to a variety of helicopter operating components, including, amoung others: lights, avionics, instruments, passenger and cargo doors, cargo hoist, and environmental control system.

The electrical system consists of the AC power system, the DC power system and lighting system. The AC system includes power generating equipment, while the DC power system includes converters and batteries, and both include the necessary controls, wiring, cables fittings, and supports to distribute the electrical power from the power source to the electrical power center.

The lighting system includes all interior and exterior lights, together with the switches, associated circuitry from the electric power center, and support hardware.

The wiring and circuitry leading from the electric power center to the various components which use electricity are included with the respective systems.

## L. AVIONICS

The avionics system consists of the integrated flight guidance and control subsystem, communication subsystem, navigation subsystem and miscellaneous equipment subsystem.

The integrated flight guidance and controls subsystem includes the auto pilot unit, the flight director unit, the gyrocompass unit, the attitude and heading reference unit, and the inertial navigation unit. These units are interdependent and may be either separate, interconnected units or one, integrated functional unit. All indicators, servomechanisms, and associated circuitry, supports, and attachments related to the integrated flight guidance and controls subsystem are also included. Although usually colocated with this subsystem, the auto-throttle/thrust management unit is part of the propulsion system because it functions to control the engine.

The communication subsystem is separated into internal and external units. The internal communication unit includes the interphone system, the public address system, and the multiplex (MUX) system. The external communication unit includes the transceiver equipment which is used for aircraft-to-aircraft or aircraft-to-ground communications.

The navigation subsystem includes all radar equipment, the automatic direction finding (ADF) unit, the distance measuring equipment (DME) unit, the doppler unit, the navigation computer units, the station-keeping unit, the

tactical air navigation (TACAN) unit, the variable omnirange (VOR) unit, the marker beacon, the instrument landing system (ILS), the collision avoidance unit (CAS), the airport traffic control (ATC) unit, the radio altimeter, the glide slope indicator, and the radar beacon unit. All the navigation units, indicators, antennae, associated circuitry and antenna coaxial cable, and the units' supports and attachments related to the navigation subsystem are included.

## M. FURNISHINGS AND EQUIPMENT

Furnishings and equipment include a variety of items in the cockpit and the passenger and/or cargo compartment. In the cockpit, this category includes all instrument and console panels, seats, insulation, lining, crew oxygen system, and cockpit door and partitions.

## N. AIR CONDITIONING AND ANTI-ICING

The air conditioning system, in addition to supplying conditioned air to the cabin, heats the cargo compartment and supplies conditioned air for avionic and electrical load center cooling.

Anti-icing functions can be performed either by hot bleed air or by electrical heat. Bleed air systems include all ducting from the main pneumatic source and inner skins, which form the hot air cavities. Electrical systems include the electrical blankets fastened to the outer surfaces of critical items, plus all wiring and controls.

In the passenger and/or cargo compartment, this category includes seats, floor covering, insulation, side panels, ceiling structure, and passenger comfort items such as galley or lavatory installations.

Miscellaneous items include the engine and cabin fire extinguisher systems, fire warning system, exterior finish, and emergency equipment (i.e., first aid kit and fire extinguisher). Cargo loading equipment is also a part of this system.

## O. LOAD AND HANDLING

This system consists of loading and handling gear, including provisions for jacking, hoisting and mooring, and ballast.

# V. RESULTS AND CONCLUSIONS

As stated earlier, the primary objective of this study was to develop a rapid and easy means for estimating system weights during the preliminary design phase. The computer programs that were developed result in acceptable estimates. The validity of the output is excellent for the intended purpose of preliminary helicopter design weight estimations. However, individual systems sometimes experience large errors in estimated system weight, as compared to actual, but when combined with the other systems that make up the helicopter the error is small. These limitations resulted from:

A. Data missing or unreliable. For example, smaller nacelles usually had no defined surface area, or an individual system was divergent from the overall system norm. Therefore, these were not included in the WER.

B. There is no definite factor that delineates between the use of skids or wheels. Empty weight of 6000 lbs was arbitrally used as the change over between skid and roll.

C. The various armed forces utilize different avionics systems. In order to obtain a precise estimate, a WER for each service would be required, resulting in additional computer inputs. Instead, the avionics WER's were averaged to produce but one input.

D. There was no factor which dictated when auxiliary power was required, therefore average aux weight was used for the cargo category WER. However, in the utility category it appeared that only helicopters with two engines had auxiliary power, therefore this was the criterior for the utility WER.

The user should utilize the enclosed example problems as initial input when working with the computer. This will insure the user that he has implemented the programs correctly or assist in debugging if incorrect. The user should insure that the HP-41CV is sized for 32 before executing any program.

# APPENDIX A

## HP41-CV COMPUTER LISTING

Replace PLUS with "+" and set SIZE 32

### A. OBS SUBROUTINE LISTING

```
01 LBL "OBS"
02 XEQ "IN"

03 LBL "P"
04 RCL 01
05 .378
06 Y1X
07 173.701
08 *
09 STO 09
10 RCL 07
11 .0135
12 *
13 E1X
14 .264
15 *
16 STO 10
17 RCL 09
18 LN
19 194.274
20 *
21 1306.779
22 -
23 STO 11
24 RCL 02
25 LN
26 408.562
27 *
28 1142.917
29 -
30 STO 12
31 RCL 09
32 .0005
33 *
34 E1X
35 2.219
36 *
37 32.414
38 -
39 RCL 10
40 LN
41 19.131
42 *
43 +
44 STO 13
45 RCL 11
46 1.917
47 Y1X
48 .00901
49 *
50 STO 14
51 RCL 09
52 -.0539
53 *
54 200.912
55 PLUS
56 STO 15
57 34
58 STO 16
59 RCL 07
60 -.0896
61 *
62 221.388
63 PLUS
64 STO 17
65 RCL 09
66 .0008
67 *
68 E1X
69 17.198
70 *
71 STO 18
72 RCL 06
73 6.5
74 /
75 1.071
76 Y1X
77 .384
```

```
78 *
79 STO 19
80 RCL 09
81 3.469
82 Y1X
83 1.281E-10
84 *
85 STO 20
86 0
87 STO 21
88 RCL 07
89 .0004
90 *
91 E1X
92 24.571
93 *
94 STO 22
95 0
96 STO 23
97 RCL 11
98 LN
99 -51.0661
100 *
101 367.947
102 +
103 STO 24
104 RCL 07
105 .003
106 *
107 E1X
108 1120.354
109 *
110 LN
111 -122.282
112 *
113 1062.004
114 PLUS
115 STO 25
116 RCL 03
117 .372
118 *
119 E1X
120 19.8
121 *
122 RCL 11
123 -.033
124 *
125 E1X
126 PLUS
127 STO 26
128 RCL 11
129 Ln
130 -22.371
131 *
132 143.396
133 PLUS
134 STO 27
135 0
136 STO 28
137 XEQ "OUT"
138 RCL 30
139 X<=0?
140 GTO 03
141 "WE?"
142 PROMPT
143 STO 01
144 XEQ "P"
145 LBL 03
146 END
```

## B. UTIL SUBROUTINE LISTING

```
01 LBL "UTIL"
02 XEQ "IN"

03 LBL "P"
04 RCL 01
05 LN
06 16239.43
07 *
08 130252.76
09 -
10 STO 09
11 RCL 07
12 .0376
13 *
14 8.106
15 -
16 STO 10
17 RCL 09
18 .000011
19 *
20 E1X
21 636.081
22 *
23 STO 11
24 RCL 02
25 11.0702
26 *
27 168.888
28 -
29 STO 12
30 RCL 09
31 .00438
32 *
33 7.061
34 -
35 RCL 10
36 2.411
37 *
38 +
39 STO 13
40 RCL 11
41 1.272
42 Y1X
43 .282
44 *
45 STO 14
46 RCL 09
47 LN
48 301.577
49 *
50 2319.89
51 -
52 STO 15
53 RCL 09
54 .000062
55 *
56 8.02
57 +
58 E1X
59 .02
60 *
61 STO 16
62 RCL 07
63 .451
64 *
65 130
66 PLUS
67 STO 17
68 RCL 07
69 LN
70 741.460
71 *
72 4542.042
73 -
74 STO 18
75 RCL 06
76 6.5
77 /
78 LN
79 363.24
80 *
81 1656.521
82 -
83 STO 19
84 RCL 09
85 .000059
86 *
87 E1X
88 210.858
89 *
90 STO 20
91 0
92 STO 21
93 RCL 07
94 LN
95 56.0975
96 *
97 312.237
98 -
```

```
99 STO 22
100 RCL 09
101 .00362
102 *
103 11.553
104 +
105 STO 23
106 RCL 11
107 LN
108 481.735
109 *
110 2794.53
111 -
112 STO 24
113 RCL 07
114 .139
115 *
116 77.823
117 +
118 STO 25
119 RCL 03
120 22
121 *
122 10
123 -
124 RCL 11
125 .175
126 *
127 +
128 STO 26
129 RCL 11
130 LN
131 122.458
132 *
133 730.252
134 -
135 STO 27
136 84.5
137 STO 28
138 RCL 01
139 6000
140 -
141 X>0?
142 GTO 01
143 RCL 09
144 .000062
145 *
146 8.02
147 +
148 E1X
149 .025
150 *
151 STO 15

152 LBL 01
153 RCL 08
154 2
155 -
156 X=/0?
157 GTO 02
158 RCL 07
159 .188
160 *
161 295
162 PLUS
163 STO 17
164 190
165 STO 21

166 LBL 02
167 XEQ "OUT"
168 RCL 30
169 X<=0?
170 GTO 03
171 "WE?"
172 PROMPT
173 STO 01
174 XEQ "P"

175 LBL 03
176 END
```

## C. CGO SUBROUTINE LISTING

```
01 LBL "CGO"
02 XEQ "IN"
03 "TANDEM?"
04 PROMPT
05 STO 31

06 LBL "P"
07 RCL 01
08 .887
09 Y1X
10 4.975
11 *
12 STO 09
13 RCL 07
14 .000145
15 *
16 E1x
17 60.127
18 *
19 STO 10
20 RCL 09
21.000045
22 *
23 E1X
24 426.378
25 *
26 STO 11
27 RCL 02
28 .00539
29 *
30 E1X
31 707.174
32 *
33 STO 12
34 RCL 07
35 .91
36 *
37 348
38 +
39 STO 17
40 RCL 09
41 LN
42 324.55
43 *
44 -3039.51
45 +
46 RCL 10
47 2.83
48 *
49 +
50 STO 13
51 RCL 11
52 2.918
53 *
54 1321.921
55 -
56 STO 14
57 RCL 31
58 X<=0?
59 GTO 01
60 0
61 STO 10
62 STO 13
63 RCL 09
64 .000041
65 *
66 E1X
67 567.688
68 *
69 STO 11
70 RCL 12
71 2
72 *
73 STO 12
74 RCL 07
75 .000198
76 *
77 E1X
78 565.507
79 *
80 STO 17
81 RCL 11
82 LN
83 3467.291
84 *
85 22118.298
86 -
87 STO 14

88 LBL 01
89 RCL 09
90 .000041
91 *
92 E1X
93 258.358
94 *
95 STO 15
96 RCL 09
97 .204
```

```
98 *
99 1.136
100 Y1X
101 .014
102 *
103 STO 16
104 RCL 07
105 .959
106 Y1X
107 .999
108 *
109 STO 18
110 RCL 06
111 6.5
112 /
113 -.0566
114 Y1X
115 454.619
116 *
117 STO 19
118 RCL 09
119 1.224
120 Y1X
121 .00334
122 *
123 STO 20
124 139.0
125 STO 21
126 RCL 07
127 LN
128 68.266
129 *
130 387.598
131 -
132 STO 22
133 RCL 09
134 1.863
135 Y1X
136 .00000663
137 *
138 STO 23
139 RCL 11
140 .539
141 Y1X
142 9.78
143 *
144 STO 24
145 RCL 07
146 LN
147 16744.967
148 *
149 108666
150 -
151 .536
152 Y1X
153 1.9
154 *
155 STO 25
156 RCL 11
157 .159
158 *
159 RCL 03
160 18.11
161 *
162 PLUS
163 STO 26
164 RCL 11
165 LN
166 117.771
167 *
168 710.594
169 -
170 STO 27
171 RCL 03
172 3.49
173 *
174 72
175 -
176 RCL 11
177 .111
178 *
179 PLUS
180 STO 28
181 XEQ "OUT"
182 RCL 30
183 X<=0?
184 GTO 03
185 "WE?"
186 PROMPT
187 STO 01
188 XEQ "P"
189 LBL 03
190 END
```

## D. OUTPUT SUBROUTINE LISTING

```
01 LBL "OUT"
02 FIX 1
03 RCL 12
04 RCL 13
05 +
06 RCL 14
07 +
08 RCL 15
09 +
10 RCL 16
11 +
12 RCL 17
13 +
14 RCL 18
15 +
16 RCL 19
17 +
18 RCL 20
19 +
20 RCL 21
21 +
22 RCL 22
23 +
24 RCL 23
25 +
26 RCL 24
27 +
28 RCL 25
29 +
30 RCL 26
31 +
32 RCL 27
33 +
34 RCL 28
35 +
36 STO 29
37 "WG EST="
38 ARCL 09
39 AVIEW
40 PROMPT
41 "ROTOR="
42 ARCL 12
43 AVIEW
44 PROMPT
45 "TAIL="
46 ARCL 13
47 AVIEW
48 PROMPT
49 "BODY="
50 ARCL 14
51 AVIEW
52 PROMPT
53 "GEAR="
54 ARCL 15
55 AVIEW
56 PROMPT
57 "NACE="
58 ARCL 16
59 AVIEW
60 PROMPT
61 "ENG="
62 ARCL 17
63 AVIEW
64 PROMPT
65 "DRIVE="
66 ARCL 18
67 AVIEW
68 PROMPT
69 "F TKS="
70 ARCL 19
71 AVIEW
72 PROMPT
73 "CNTR="
74 ARCL 20
75 AVIEW
76 PROMPT
77 "AUX="
78 ARCL 21
79 AVIEW
80 PROMPT
81 "INST="
82 ARCL 22
83 AVIEW
84 PROMPT
85 "HYD="
86 ARCL 23
87 AVIEW
88 PROMPT
89 "ELEC="
90 ARCL 24
91 AVIEW
92 PROMPT
93 "AVIN="
94 ARCL 25
95 AVIEW
96 PROMPT
97 "FRN="
98 ARCL 26
99 AVIEW
```

```
100 PROMPT
101 "AIAC="
102 ARCL 27
103 AVIEW
104 PROMPT
105 "IH="
106 ARCL 28
107 AVIEW
108 PROMPT
109 "REV WE="
110 ARCL 29
111 AVIEW
112 PROMPT
113 RCL 29
114 RCL 06
115 PLUS
116 RCL 04
117 PLUS
118 RCL 05
119 PLUS
120 STO 31
121 "REV WG="
122 ARCL 31
123 AVIEW
124 PROMPT
125 FIX 3
126 "AGAIN?"
127 PROMPT
128 STO 30
129 END
```

## E. INPUT SUBROUTINE LISTING

```
01 LBL "IN"
02 "WE?"
03 PROMPT
04 STO 01
05 "S?"
06 PROMPT
07 STO 02
08 "P?"
09 PROMPT
10 STO 03
11 "PWT?"
12 PROMPT
13 STO 04
14 "CGC?"
15 PROMPT
16 STO 05
17 "F?"
18 PROMPT
19 STO 06
20 "SHP?"
21 PROMPT
22 STO 07
23 "NENG?"
24 PROMPT
25 STO 08
26 END
```

## F. LISTING OF CALCULATOR DISPLAYS

| DISPLAY | EXPLANATION | WER NOTATION |
|---|---|---|
| WE? | Prompt: initial empty weight (lbs) | We |
| S? | Prompt: main rotor planform area (sq ft) | S |
| P? | Prompt: total number of personnel | People |
| PWT? | Prompt: weight of personnel (lbs) | Weight |
| CGO? | Prompt: weight of baggage and cargo (lbs) | Cargo |
| F? | Prompt: total weight of fuel (LBS) | Fuel |
| SHP? | Prompt: shaft horsepower (lbs) | HP |
| NENG? | Prompt: number of engines | Neng |
| TANDEM? | Prompt: helicopter tandem?; 1-Yes, 0-No | Tandem |
| AGAIN? | Prompt: another run desired?; 1-Yes, 0-No | -- |
| WG EST= | Answer: gross weight estimate (lbs) | Wg |
| ROTOR= | Answer: main rotor blade weight (lbs) | W1 |
| TAIL= | Answer: tail rotor/structure weight (lbs) | W2 |
| BODY= | Answer: body structure weight (lbs) | W3 |
| GEAR= | Answer: landing gear weight (lbs) | W4 |
| NACE= | Answer: nacelle weight (lbs) | W5 |
| ENG= | Answer: engine weight (lbs) | W6A |
| DRIVE= | Answer: drive train weight (lbs) | W6B |
| F TKS= | Answer: weight of fuel cells (lbs) | W6C |
| CNTR= | Answer: flight control weight (lbs) | W7 |
| AUX= | Answer: auxiliary power system (Lbs) | W8 |
| INSI= | Answer: instruments | W9 |
| HYD= | Answer: hydaulic system (lbs) | W10 |
| ELEC= | Answer: electrical system | W11 |
| AVIN= | Answer: avionics system (lbs) | W12 |
| FRN= | Answer: furnishings and equipment (lbs) | W13 |
| AIAC= | Answer: anti-ice and air cond. (lbs) | W14 |
| LH= | Answer: load and handling (lbs) | W15 |
| REV WE= | Answer: WE using above computed values | -- |
| REV WG= | Answer: Sum of P, PWT, CGO, and REV WE | -- |

## G. STORAGE ALLOCATIONS

| Storage Register Number | Contents |
|---|---|
| 01 | WE |
| 02 | S |
| 03 | P |
| 04 | PWT |
| 05 | CGO |
| 06 | F |
| 07 | SHP |
| 08 | NENG |
| 09 | Wg |
| 10 | Stt |
| 11 | Sb |
| 12 | W1 |
| 13 | W2 |
| 14 | W3 |
| 15 | W4 |
| 16 | W5 |
| 17 | W6A |
| 18 | W6B |
| 19 | W6C |
| 20 | W7 |
| 21 | W8 |
| 22 | W9 |
| 23 | W10 |
| 24 | W11 |
| 25 | W12 |
| 26 | W13 |
| 27 | W14 |
| 28 | W15 |
| 29 | RWE |
| 30 | K |
| 31 | Tandem/RWG |

# APPENDIX B

## IBM 3033 COMPUTER LISTING

### A. MAIN PROGRAM

```
C               VARIABLES AND CONSTANTS
C         ***********************************
C
C     RWE       REVISED EMPTY WEIGHT
C     WE        INITIAL EMPTY WEIGHT
C     WG        ESTIMATED GROSS WEIGHT
C     WG1       YOUR GROSS WEIGHT
C     W1        MAIN ROTOR BLADE
C     W2        TOTAL TAIL SECTION
C     W2A       TAIL ROTOR BLADE
C     W2B       TAIL STRUCTURE
C     W3        BODY
C     W4        LANDING GEAR
C     W5        NACELLE
C     W6        TOTAL PROPULSION SYSTEM
C     W6A       ENGINE
C     W6B       DRIVE
C     W6C       FUEL CELLS
C     W7        FLIGHT CONTROLS
C     W8        AUXILIARY POWER
C     W9        INSTRUMENTS
C     W10       HYDRAULICS
C     W11       ELECTRICAL
C     W12       AVIONICS
C     W13       FURNISHING AND EQUIPMENT
C     W14       ANTI-ICE AND AIR-CONDITIONING
C     W15       LOADING AND HANDLING
C     CARGO     TOTAL WEIGHT OF CARGO AND BAGGAGE
```

```
C     WEIGHT  TOTAL WEIGHT OF PERSONNEL
C     PEOPLE  TOTAL NUMBER OF PERSONNEL
C     S       MAIN ROTOR BLADE PLANFORM AREA(SQ FT)
C     NENG    NUMBER OF ENGINES
C     HP      SHAFT HORSEPOWER
C     FUEL    TOTAL ON BOARD FUEL CAPACITY (LBS)
C     CREWWT  ACTUAL WEIGHT OF CREW PERSONNEL ONLY
C     RERUN   INTEGER INPUT FOR RERUNNING PROGRAM
C     COUNT   COUNTER FOR PAGE OUTPUT
C     TANDEM  IF 1 THEN HELICOPTER IS TANDEM
C     K       CONSTANT (INITIAL EMPTY WEIGHT minus
C                   REVISED EMPTY WEIGHT)
C
C             MAIN PROGRAM
C        *****************************
C
      INTEGER RERUN
10    CALL FRTCMS ('CLRSCRN ')
      WRITE (6,20)
      READ (5,*) TYPE
      IF (TYPE.EQ.1) CALL OBS
      IF (TYPE.EQ.2) CALL UTILTY
      IF (TYPE.EQ.3) CALL CARGO
C     CALL FRTCMS ('CLRSCRN ')
      WRITE (6,30)
      READ (5,*) RERUN
      IF (RERUN.EQ.1) GO TO 10
      STOP
20    FORMAT('WHAT TYPE OF HELICOPTER ARE YOU DESIGNING ?
     */4x,15h 1 cBSERVATION /,4X,11H 2 UTILITY
     */4X,9H 3 CARGO /18H ENTER 1, 2, OR 3)
30    FORMAT(30H DO YOU WANT ANOTHER RUN ?
      11H   1 - YES /39h                      0 - no)
      END
```

## B. OBSERVATION SUBROUTINE

```
      SUBROUTINE OBS
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
C
10    WG=173.701*WE**.378
      STT=.264*EXP(.0135*HP)
      SB=194.274*ALOG(WG)-1306.779
      W1=408.5622*ALOG(S)-1142.917
      W2A=2.219*EXP(.0005 * WG)
      W2B=19.131*ALOG(STT)-32.414
      W2=W2A+W2B
      W3=.0090*SB**1.917
      W4=-.0539*WG+200.912
      W5=34.0
      W6A=-.0896*HP+221.388
      W6B=17.190*EXP( .0008 * WG)
      W6C=.384*(FUEL/6.5)**1.0710
      W6=W6A+W6B+W6C
      W7=.000000000128*WG**3.469
      W8=0.0
      W9=24.571*EXP(.00040* HP)
      W10=0.0
      W11=-51.068*ALOG(SB)+367.947
      W12=-122.282*ALOG( 1120.354 * EXP( .003 * HP))
     * +1062.00451
      W13=19.80*(EXP(.372*PEOPLE) + EXP(-.033*SB))
      W14=-22.371*ALOG(SB)+143.396
      W15=0.0
```

```
      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10
 20   RETURN
      END
```

## C. UTILITY SUBROUTINE

```
      SUBROUTINE UTILTY
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
C
10    WG=16239.430*ALOG(WE)-130252.750
      STT=.0376*HP-8.106
      SB=636.081*EXP(.000011 * WG)
      W1=11.0702*S-168.888
      W2A=.00438*WG+12.470
      W2B=2.411*STT-19.531
      W2=W2A+W2B
      W3=.282*SB**1.272
      W4 = 301.577 * ALOG(WG)-2319.890
      IF(WE.LE.6000)W4=.025*EXP(.000062*WG +8.02)
      W5=.02*EXP(.000062 * WG +8.02)
      W6A=130.0+.451*HP
      IF (NENG.EQ.2) W6A=295.0+.188*HP
      W6B=741.460*ALOG(HP)-4542.0420
      W6C=363.240*ALOG(FUEL/6.5)-1656.521
      W6=W6A+W6B+W6C
      W7=210.858*EXP(.000059 * WG)
```

```
      W8=0.0
      IF(NENG.EQ.2) W8 = 190.0
      W9=56.0975*ALOG(HP)-312.237
      W10=.00362*WG+11.553
      W11=481.735*ALOG(SB)-2794.530
      W12=.139*HP+77.823
      W13=.175*SB+22.0*PEOPLE-10.
      W14=122.458*ALOG(SB)-730.252
      W15=84.50
C
      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10
20    RETURN
C
      END
```

## D. CARGO SUBROUTINE

```
      SUBROUTINE CARGO
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
      WRITE(6,71)
      READ(5,*) TANDEM
      IF(TANDEM.EQ.1.)WRITE(8,72)
      IF(TANDEM.EQ.0.)WRITE(8,73)
C
10    WG=4.975*WE**.887
      STT=60.127*EXP(.000145*HP)
```

```
      SB=426.378*EXP(.000045 * WG)
      W1=707.174*EXP(.00539*S)
      W6A = 348.0 + .910*HP
      W2A=324.550*ALOG(WG)-3021.510
      W2B=-18.0+2.83*STT
      W3=2.918*SB-1321.921
      IF(TANDEM.NE.1.)GO TO 45
      STT=0.0
      SB = 567.688*EXP(.000041*WG)
      W1 =2*W1
      W2A=0.0
      W2B=0.0
      W3=3467.291*ALOG(SB)-22118.298
      W6A=565.507*EXP(.000198*HP)
C
45    W2=W2A+W2B
      W4=258.358*EXP(.000041*WG)
      W5=.014*(.204 * WG )**1.136
      W6B=.999*HP**.959
      W6C=454.619*(FUEL/6.5)**(-.0566)
      W6=W6A+W6B+W6C
      W7=.00334*WG**1.224
      W8=139.0
      W9=68.266*ALOG(HP)-387.598
      W10=.00000663*WG**1.863
      W11=9.780*SB**.539
      W12=1.90*(16744.967*ALOG(HP)-108666.0)**.536
      W13=.159*SB+18.11*PEOPLE
      W14=117.771*ALOG(SB)-710.594
      W15=-72.0+.111*SB+3.490*PEOPLE


      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
```

```
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10


71    FORMAT(' ARE YOU DESIGNING A TANDEM HELICOPTER ?
     *1 - YES/'                                  0 - NO')
72    FORMAT(T16,'A TANDEM HELICOPTER IS BEING
     *DESIGNED//)
73    FORMAT(T15,'A TANDEM HELICOPTER IS NOT BEING
     *designed//)
C
20    RETURN
      END
```

## E. OUTPUT SUBROUTINE

```
      SUBROUTINE OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,
     *W6C,W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      REAL K
      INTEGER COUNT
      RWE=W1+W2+W3+W4+W5+W6+W7+W8+W9+W10+W11+W12+W13
     *W14+W15
      CREWWT=WEIGHT+CARGO
      WG1=RWE+FUEL+CREWWT
      K=WE-RWE
      CALL FRTCMS ('CLRSCRN ')
      WRITE (6,210) WE
      WRITE (8,210) WE
      WRITE (6,220) WG
      WRITE (8,220) WG
      WRITE (6,230) W1,W2
      WRITE (8,230) W1,W2
      WRITE (6,240) W3,W4
      WRITE (8,240) W3,W4
      WRITE (6,250) W5,W6A
```

```
      WRITE (8,250) W5,W6A
      WRITE (6,260) W6B,W6C
      WRITE (8,260) W6B,W6C
      WRITE (6,270) W7,W8
      WRITE (8,270) W7,W8
      WRITE (6,280) W9,W10
      WRITE (8,280) W9,W10
      WRITE (6,290) W11,W12
      WRITE (8,290) W11,W12
      WRITE (6,300) W13,W14
      WRITE (8,300) W13,W14
      WRITE (6,310) W15
      WRITE (8,310) W15
      WRITE (6,320) RWE
      WRITE (8,320) RWE
      WRITE (6,330) CREWWT,FUEL
      WRITE (8,330) CREWWT,FUEL
      WRITE (6,340) WG1
      WRITE (8,340) WG1
      IF (ABS(K) .LE. .02 * WE) GO TO 20
      WRITE (6,350)
      WRITE (8,350)
      WRITE (6,360)
      READ (5,*) N
      WRITE (8,370)
      COUNT=COUNT+1
      IF (COUNT.EQ.3) WRITE (8,380)
      IF (N.EQ.1) WE=RWE
C
20    RETURN
C
210   FORMAT(T15,'EMPTY WEIGHT ESTIMATE (LBS) = ,F11.3)
220   FORMAT(T15,'GROSS WEIGHT ESTIMATE (LBS) = ,F11.3/)
230   FORMAT('ROTOR =,T21,F8.3,T35,'TAIL=,T50,F8.3)
```

```
240    FORMAT('BODY = ,T21,F8.3,T35,'LANDING GEAR=,T50,
      *F8.3)
250    FORMAT('NACELLE = ,T21,F8.3,T35,'ENGINE = ,T50,
      *F8.3)
260    FORMAT('DRIVE = ,T21,F8.3,T35,'FUEL TANKS = ,T50,
      *F8.3)
270    FORMAT('FLIGHT CONTROLS = ,T21,F8.3,T35,
      *'AUX POWER = ,T50,F8.3)
280    FORMAT('INSTRUMENTS = ,T21,F8.3,T35,'HYDAULICS = ,
      *T50,F8.3)
290    FORMAT('ELECTRICAL = ,T21,F8.3,T35,'AVIONICS = ,
      *T50,F8.3)
300    FORMAT('FURNISHINGS = ,T21,F8.3,T35,'ICE AND AIR=,
      *T50,F8.3)
310    FORMAT(21H LOAD AND HANDLING = ,T21,F8.3,/)
320    FORMAT(T10,24H REVISED EMPTY WEIGHT = ,F11.3)
330    FORMAT('PERSONNEL & CARGO = ,T22,F8.3,T35,'FUEL =,
      *F8.3/)
340    FORMAT(T10,21H YOUR GROSS WEIGHT = ,F11.3/)
350    FORMAT (T5,53HINITIAL AND REVISED EMPTY WEIGHT VARY
      *BY MORE THAN 2%)
360    FORMAT (' FOR RECYCYLE, ENTER 1  --  OTHERWISE  0')
370    FORMAT (////)
380    FORMAT (1H 1)
       END
```

## F. INPUT SUBROUTINE

```
       SUBROUTINE INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,
      *HP,ENG)
       REAL NENG
       CALL FRTCMS ('CLRSCRN ')
       WRITE (8,380)
       WRITE (8,30)
```

```
      WRITE (6,40)
      READ (5,*) WE
      WRITE (8,50) WE
      WRITE (6,60)
      READ (5,*) S
      WRITE (8,70) S
      WRITE (6,80)
      READ (5,*) PEOPLE
      WRITE (8,90) PEOPLE
      WRITE (6,100)
      READ (5,*) WEIGHT
      WRITE (8,110) WEIGHT
      WRITE (6,120)
      READ (5,*) CARGO
      WRITE (8,130) CARGO
      WRITE (6,140)
      READ (5,*) FUEL
      WRITE (8,150) FUEL
      WRITE (6,160)
      READ (5,*) HP
      WRITE (8,170) HP
      CALL FRTCMS ('CLRSCRN ')
      WRITE (6,190)
      READ (5,*) NENG
      WRITE (8,200) NENG
      WRITE (8,180)
      RETURN
30    FORMAT (T10,46H *** INITIAL INPUT ***********,//)
40    FORMAT('ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)')
50    FORMAT('INITIAL EMPTY WEIGHT ESTIMATE (LBS)=,F11.3')
60    FORMAT (34H ENTER BLADE PLANFORM AREA(SQ FT) )
70    FORMAT (31H BLADE PLANFORM AREA (SQ FT) = ,F8.3)
80    FORMAT (32H ENTER NUMBER CREW + PASSENGERS )
90    FORMAT (28H NUMBER CREW + PASSENGERS = ,F3.0)
100   FORMAT (39H ENTER TOTAL WEIGHT OF PERSONNEL (LBS))
```

```
110    FORMAT (29H TOTAL WEIGHT OF PERSONNEL = ,F8.3)
120    FORMAT('ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)')
130    FORMAT (' TOTAL WEIGHT OF BAGGAGE/CARGO = ',F8.3)
140    FORMAT (27H ENTER FUEL CAPACITY (LBS) )
150    FORMAT (21H FUEL CAPACITY (LBS) ,F8.3)
160    FORMAT (24H ENTER SHAFT POWER (HP) )
170    FORMAT (18H SHAFT POWER (HP) ,F11.3)
180    FORMAT (T10,'****** WEIGHT ESTIMATE *********',//)
190    FORMAT (34H ENTER NUMBER OF ENGINES (1 OR 2 ))
200    FORMAT (21H NUMBER OF ENGINES = ,F2.0///)
380    FORMAT (1H1)
       END
```

## G. WT EXEC

```
                         WT

THIS FILE COMPILES AND EXECUTES THE PROGRAM WEIGHT
GIVE THE COMMAND "WT <FILENAME> <DEVICE>"
GLOBAL TXTLIB CMSLIB FORTMOD2 MOD2EEH NONIMSL
GLOBAL IMSLSP IMSLDP
FORTGI &1
FILEDEF 05 TERM
FILEDEF 06 TERM
FILEDEF 08 DISK AIR LISTING
LOAD &1 (START)
&END
```

# APPENDIX C

## HP41-CV EXAMPLE PROGRAMS

This section contains example programs for three helicopter categories.

### A. OBS SUBROUTINE PROGRAM

This subroutine is for designing light observation helicopters.

1. Read the following cards into your calculator:
   - a. Input
   - b. Output
   - c. Obs
2. Execute the following instructions in order.

"XEQ OBS"

| PROMPT | ENTER | PRESS |
|---|---|---|
| WE? | 1502 | R/S |
| S? | 31.3 | R/S |
| P? | 3 | R/S |
| PWT? | 600 | R/S |
| CGO? | 20 | R/S |
| F? | 499 | R/S |
| SHP? | 317 | R/S |
| NENG? | 1 | R/S |

After approximately twenty seconds the following output will be displayed.

```
           DISPLAY                                  PRESS

    WG EST=  2757.9                                  R/S
    ROTOR=   264.0                                   R/S
    TAIL=    32.8                                    R/S
    BODY=    309.8                                   R/S
    GEAR=    52.3                                    R/S
    NACE=    34.0                                    R/S
    ENG=     193.0                                   R/S
    DRIVE=   156.1                                   R/S
    F TKS=   40.1                                    R/S
    CNTR=    110.4                                   R/S
    AUX=     0.0                                     R/S
    INST=    27.9                                    R/S
    HYD=     0.0                                     R/S
    ELECT=   89.7                                    R/S
    AVIN=    87.1                                    R/S
    FRN=     60.4                                    R/S
    AIAC=    21.5                                    R/S
    LH=      0.0                                     R/S
    REV WE=  1478.8                                  R/S
    REV WG=  2597.8                                  R/S
    AGAIN?    For another run enter 1                R/S
              If not enter 0
```

## B. UTIL SUBROUTINE PROGRAM

This subroutine is for designing military utility helicopters.

1. Read the following cards into your calculator:
    a. Input
    b. Output
    c. UTIL
2. Execute the following instructions in order.

"XEQ UTIL"

| PROMPT | ENTER | PRESS |
|---|---|---|
| WE? | 5200 | R/S |
| S? | 77.8 | R/S |
| P? | 13 | R/S |
| PWT? | 2600 | R/S |
| CGO? | 0 | R/S |
| F? | 1388 | R/S |
| SHP? | 1150 | R/S |
| NENG? | 1 | R/S |

After approximately twenty seconds the following output will be displayed.

| DISPLAY | PRESS |
|---|---|
| WG EST= 8698.5 | R/S |
| ROTOR= 692.4 | R/S |
| TAIL= 115.7 | R/S |
| BODY= 1172.7 | R/S |
| GEAR= 130.4 | R/S |
| NACE= 104.3 | R/S |
| ENG= 648.7 | R/S |
| DRIVE= 683.4 | R/S |
| F TKS= 291.8 | R/S |
| CNTR= 352.3 | R/S |
| AUX= 0.0 | R/S |
| INST= 83.1 | R/S |
| HYD= 43.0 | R/S |
| ELECT= 361.3 | R/S |
| AVIN= 237.7 | R/S |
| FRN= 398.5 | R/S |
| AIAC= 72.0 | R/S |
| LH= 84.5 | R/S |
| REV WE= 5471.7 | R/S |
| REV WG= 9459.7 | R/S |
| AGAIN? For another run enter 1<br>If not enter 0 | R/S |

## C. CGO SUBROUTINE PROGRAM

This subroutine is for designing military cargo helicopters.

1. Read in the following cards into your calculator:
    a. Input
    b. Output
    c. CGO
2. Execute the following instructions in order.

"XEQ CGO"

| PROMPT | ENTER | PRESS |
|---|---|---|
| WE? | 7700 | R/S |
| S? | 127.3 | R/S |
| P? | 18 | R/S |
| PWT? | 3600 | R/S |
| CGO? | 200 | R/S |
| F? | 1750 | R/S |
| SHP? | 1535 | R/S |
| NENG? | 1 | R/S |
| TANDEM? | 0 No | R/S |

After approximately twenty seconds the following output will be displayed.

```
           DISPLAY                                PRESS

    WG EST=  13935.1                               R/S
    ROTOR=   1404.5                                R/S
    TAIL=    270.0                                 R/S
    BODY=    1007.3                                R/S
    GEAR=    457.5                                 R/S
    NACE=    117.4                                 R/S
    ENG=     1744.9                                R/S
    DRIVE=   1135.1                                R/S
    F TKS=   331.2                                 R/S
    CNTR=    394.6                                 R/S
    AUX=     139.0                                 R/S
    INST=    113.2                                 R/S
    HYD=     34.8                                  R/S
    ELECT=   358.6                                 R/S
    AVIN=    319.2                                 R/S
    FRN=     452.9                                 R/S
    AIAC=    76.4                                  R/S
    LH=      79.4                                  R/S
    REV WE=  8435.9                                R/S
    REV WG= 13985.9                                R/S
    AGAIN?    For another run enter 1              R/S
              If not enter 0
```

# APPENDIX D

## IBM 3033 EXAMPLE PROGRAMS

This section contains example programs for all three helicopter categories. This program contains all subroutines in one interactive file named "Weight". The program must be compiled, then loaded before it will execute. To assist in this procedure an exec "WT" has been provided. Simply go to your flist and write, "wt" next to the program "Weight". Upon completion, just answer the questions with desired input. The following is a listing of "Weight" input and output for all three type helicopters.

### A. OBSERVATION HELICOPTER

#### 1. Input

| SCREEN DISPLAY | ENTER |
|---|---|
| WHAT TYPE OF HELICOPTER ARE YOU DESIGNING? | |
| 1 OBSERVATION | |
| 2 UTILITY | |
| 3 CARGO | |
| ENTER 1,2 or 3.? | 1 |
| ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)? | 1502 |
| ENTER BLADE PLANFORM AREA(SQ FT)? | 31.3 |
| ENTER NUMBER CREW + PASSENGERS? | 3 |
| ENTER TOTAL WEIGHT OF PERSONNEL (LBS)? | 600 |
| ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)? | 20 |
| ENTER FUEL CAPACITY (LBS)? | 499 |
| ENTER SHAFT POWER (HP)? | 317 |
| ENTER NUMBER OF ENGINES (1 OR 2 )? | 1 |

2. Output

The output will be located on your "A disk" under file name "Air Listing".

```
          *************** INITIAL INPUT ****************


INITIAL EMPTY WEIGHT ESTIMATE (LBS) =     1502.000
BLADE PLANFORM AREA (SQ FT) =   31.300
NUMBER CREW + PASSENGERS =  3.
TOTAL WEIGHT OF PERSONNEL =  600.000
TOTAL WEIGHT OF BAGGAGE/CARGO =   20.000
FUEL CAPACITY (LBS)  499.000
SHAFT POWER (HP)     317.000
NUMBER OF ENGINES = 1.


          *************** WEIGHT ESTIMATE ****************


              EMPTY WEIGHT ESTIMATE (LBS) =    1502.000
              GROSS WEIGHT ESTIMATE (LBS) =    2757.933

ROTOR =                 264.015      TAIL =             32.789
BODY =                  309.014      LANDING GEAR =     52.259
NACELLE =                34.000      ENGINE =          192.985
DRIVE =                 156.128      FUEL TANKS =       40.121
FLIGHT CONTROLS =       110.303      AUX POWER =         0.0
INSTRUMENTS =            27.893      HYDAULICS =         0.0
ELECTRICAL =             89.737      AVIONICS =         87.124
FURNISHINGS =            60.451      ICE AND AIR =      21.518
LOAD AND HANDLING =       0.0

          REVISED EMPTY WEIGHT =    1478.335
PERSONNEL & CARGO =  620.000      FUEL =  499.000

          YOUR GROSS WEIGHT =    2597.335
```

## B. UTILITY HELICOPTER

### 1. Input

```
              SCREEN DISPLAY                                    ENTER

WHAT TYPE OF HELICOPTER ARE YOU DESIGNING?
                 1   OBSERVATION
                 2   UTILITY
                 3   CARGO
ENTER 1,2 or 3.?                                            2
ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)?                  5200
ENTER BLADE PLANFORM AREA(SQ FT)?                           77.8
ENTER NUMBER CREW + PASSENGERS?                             13
ENTER TOTAL WEIGHT OF PERSONNEL (LBS)?                      2600
ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)?                  0
ENTER FUEL CAPACITY (LBS)?                                  1388
ENTER SHAFT POWER (HP)?                                     1150
ENTER NUMBER OF ENGINES (1 OR 2 )?                          1
```

### 2. Output

The output will be located on your "A disk" under file name "Air Listing".

```
              ************** INITIAL INPUT ***************


 INITIAL EMPTY WEIGHT ESTIMATE (LBS) =    5200.000
 BLADE PLANFORM AREA (SQ FT) =   77.800
 NUMBER CREW + PASSENGERS = 13.
 TOTAL WEIGHT OF PERSONNEL = 2600.000
 TOTAL WEIGHT OF BAGGAGE/CARGO =    0.0
 FUEL CAPACITY (LBS) 1388.000
 SHAFT POWER (HP)    1150.000
 NUMBER OF ENGINES = 1.
```

```
        ************** WEIGHT ESTIMATE ****************

            EMPTY WEIGHT ESTIMATE (LBS) =    5200.000
            GROSS WEIGHT ESTIMATE (LBS) =    8698.500

ROTOR =               692.373      TAIL =            115.746
BODY =               1172.667      LANDING GEAR =    130.377
NACELLE =             104.301      ENGINE =          648.650
DRIVE =               683.406      FUEL TANKS =      291.832
FLIGHT CONTROLS =     352.269      AUX POWER =         0.0
INSTRUMENTS =          83.111      HYDAULICS =        43.042
ELECTRICAL =          361.321      AVIONICS =        237.673
FURNISHINGS =         398.491      ICE AND AIR =      71.971
LOAD AND HANDLING =    84.500

        REVISED EMPTY WEIGHT =    5471.719
PERSONNEL & CARGO = 2600.000      FUEL = 1388.000

        YOUR GROSS WEIGHT =    9459.719

   INITIAL AND REVISED EMPTY WEIGHT VARY BY MORE THAN 2%
```

## C. CARGO HELICOPTER

### 1. Input

```
          SCREEN DISPLAY                                  ENTER

WHAT TYPE OF HELICOPTER ARE YOU DESIGNING?
                1   OBSERVATION
                2   UTILITY
                3   CARGO
ENTER 1,2 or 3.?                                      3
ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)?            7700
ENTER BLADE PLANFORM AREA(SQ FT)?                     127.3
ENTER NUMBER CREW + PASSENGERS?                       18
ENTER TOTAL WEIGHT OF PERSONNEL (LBS)?                3600
ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)?            200
ENTER FUEL CAPACITY (LBS)?                            1750
ENTER SHAFT POWER (HP)?                               1535
ENTER NUMBER OF ENGINES (1 OR 2 )?                       1
ARE YOU DESIGNING A TANDEM HELICOPTER? 1 YES, 0 NO       0
```

### 2. Output

The output will be located on your "A disk" under file name "Air Listing".

```
          ************** INITIAL INPUT ***************


 INITIAL EMPTY WEIGHT ESTIMATE (LBS) =     7700.000
 BLADE PLANFORM AREA (SQ FT) =  127.300
 NUMBER CREW + PASSENGERS = 18.
 TOTAL WEIGHT OF PERSONNEL = 3600.000
 TOTAL WEIGHT OF BAGGAGE/CARGO =  200.000
 FUEL CAPACITY (LBS) 1750.000
 SHAFT POWER (HP)    1535.000
 NUMBER OF ENGINES = 1.
```

```
              ************** WEIGHT ESTIMATE ****************

                  A TANDEM HELICOPTER IS NOT BEING DESIGNED


                  EMPTY WEIGHT ESTIMATE (LBS) =    7700.000
                  GROSS WEIGHT ESTIMATE (LBS) =   13935.105

ROTOR =               1404.482      TAIL =              269.979
BODY =                1007.335      LANDING GEAR =  457.458
NACELLE =              117.375      ENGINE =           1744.850
DRIVE =               1135.124      FUEL TANKS =     331.209
FLIGHT CONTROLS =   394.582      AUX POWER =        139.000
INSTRUMENTS =        113.221      HYDAULICS =         34.833
ELECTRICAL =         358.581      AVIONICS =         319.190
FURNISHINGS =        452.899      ICE AND AIR =       76.399
LOAD AND HANDLING =  79.424

              REVISED EMPTY WEIGHT =     8435.922
PERSONNEL & CARGO = 3800.000     FUEL = 1750.000

              YOUR GROSS WEIGHT =    13985.922

   INITIAL AND REVISED EMPTY WEIGHT VARY BY MORE THAN 2%
```

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